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An indicator set to track resilience to climate change in agriculture: A policy-maker's perspective

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ABSTRACT

Resilience-based approaches to climate change have yet to be widely applied in agriculture. In this sector, indicators have been centered on the impacts of climate on production systems, crops, yields, infrastructure, financial performance, farmers' livelihoods and food security. This paper focuses on designing an indicator set to capture the resilience of agriculture to inform decision-making frameworks and policies. The indicators' selection and definition were driven by their relevance for decision-making through the combined knowledge of policy and information priorities on climate change impacts and vulnerabilities as well as pragmatic issues relating to data availability. In total, 36 indicators were selected covering the following areas: regional drivers of the change to the agricultural sector (demographics, agricultural markets, climate); farmland production activities (food and feed); non-farm economy; and primary outcomes (off-farm net income, numerous environmental services). By coordinating this process among policy-makers with different roles in regional planning, we were able to identify shared information needs among the various sectoral representatives. The indicator selection process also captured policy gaps potential responses that could increase resilience and feed directly into policy reviews, thereby strengthening integration of actions across sectors. This indicator set emphasizes that the relationships between government agencies and both industry and academia may be improved by addressing gaps in data availability, accessibility, and privacy constraints.

1. Introduction

Climate change impacts, vulnerability assessments and adaptation planning have become integral parts of ongoing policy-making processes (Intergovernmental Panel on Climate Change, 2012). Although there are relatively few examples of legislated actions for climate change adaptation, planning for resilience to climate change is now routinely taken into account when designing policies and systems that can better deal with uncertainty (Kärrholm et al., 2014; Moraci et al., 2016). Indicators represent a critical part of the toolbox for policy-makers to characterize, develop and assess planning efforts (Department of Environment, Food and Rural Affairs, 2010). Two important uses for indicators are in: i) identifying specific vulnerabilities and gaps in resilience with regard to a specific objective, which allows targeted policies to be defined and ii) evaluating the effectiveness of adaptation actions or programs in conferring greater resilience (Chen et al., 2016; Department of Environment, Food and Rural Affairs, 2010; Ford et al., 2013).

Over the last decade, considerable effort has been made to monitor the vulnerability of human and natural systems to climate change (Weber et al., 2015). A number of indicators have been designed to capture aspects of a given system's exposure or sensitivity to climatic conditions (Chen et al., 2016; Weber et al., 2015). Often, these take the form of climate indicators tracking aspects such as precipitation (amounts and intensity) and temperature extremes (Moraci et al., 2016; Suresh, 2016). In such cases, the vulnerabilities or risk to socio-ecological systems are represented in terms of how they would be affected by particular large scale events (e.g., drought, monsoons). This emphasis on impacts stops short of evaluating how socioecological systems will be able to react to or recover from such impacts. It also fails to provide sufficiently detailed information to enable planners to identify and prioritize between emerging or potential risks (e.g., how frequently extremes will exceed critical thresholds).

Adaptive capacity adds another layer of detail to planning, by

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considering how well structured—and effective—institutions, networks and individuals are in responding to impacts; this includes, for example, the availability of financial resources, appropriate technologies, human capacities and skills (Arnott et al., 2016; Spiller, 2016; Swanson and Bhadwal, 2009). In general, but especially in the case of climate change, adaptive capacity indicators must measure the capacity to respond to exposures. This should be considered from the perspective of past and present conditions, to establish overall trends and allow forward-looking estimates of change to be derived from the climate models (Arnott et al., 2016; Weber et al., 2015). As such, these exposures also need to be considered from the perspective of their individual impacts on socioecological systems.

Climate change impacts are in and of themselves less important than the ability of socioecological systems to withstand such impacts. The term resilience is widely used in relation to climate change and disaster risk reduction (United Nations International Strategy for Disaster Reduction, 2012; World Bank, 2010), but few guidelines link prescriptive actions with specific qualities of resilience (Bizikova et al., 2015; O'Connell et al., 2015). Resilience is the capacity of a socioecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning and adaptation (Holling, 1973; Gunderson and Holling, 2002; Walker et al., 2004). In this way, examining resilience means considering how complex adaptive systems change at multiple intersecting scales (O'Connell et al., 2015). Although expansive, this view is practical because it unites many existing indicators currently in use for different aspects of climate change vulnerability assessment - ranging from impact and adaptation at policy and governance levels to more specific sectoral concerns, such as agriculture, health, environmental conservation and urban development (Bizikova et al., 2015; Tyler and Moench, 2012; Berkes, 2007). In this context, resilience indicators help to assess vulnerability and adaptive capacity, with the major difference that they consider socioeconomic systems as dynamic and interactive, not just as a single response to some climate related impact. This extends impacts from the more traditional single disciplinary measure to a more holistic set of measures, thereby increasing relevance to a range of different governance, policy and planning objectives (Bizikova et al., 2015; Tyler and Moench, 2012; O'Connell et al., 2015).

To date, resilience-based approaches have yet to be widely applied by certain sectors. Within resource sectors such as agriculture, indicators in the literature focus largely on the impacts of climate in terms of economics; this translates into losses or gains in production systems, and available resources or technologies for adapting to emerging risk/impacts (e.g., see Swanson and Bhadwal, 2009; Organisation for Economic Co-operation and Development (OECD), 2013). Other indicators focus on more specific impacts, such as changes in the status of soils, planted crops, yields, infrastructure, financial performance, farmers' livelihoods and food security (Organisation for Economic Co-operation and Development (OECD), 2013; Swanson and Bhadwal, 2009). Yet, impacts on agriculture—and agricultural practices—can also affect other important aspects of regional socioeconomic systems, including water management (and contamination), human health, and wildlife habitat and disease (Bizikova et al., 2015; Institute of Medicine & National Research Council, 2015).

From a governance perspective, such interdependencies among different sectors are problematic, complicating decisions regarding how to implement and monitor adaptation strategies to increase overall resilience. This can confound action at the local scale, where adaptation actions are most often implemented (Intergovernmental Panel on Climate Change, 2012), because at this scale activities are significantly challenged by capacity shortages (Berkes, 2007). In fact, this continues to be a problem even when adaptation actions are directed through more central national or regional policy and/or legislation (Department of Environment, Food and Rural Affairs, 2010). Local adaptation is further confounded by the reality that many of the important drivers of potential climate change impacts often depend on factors outside regional control, adding yet more uncertainty to regional adaptive planning (e.g., global markets, fuel prices) (Arnott et al., 2016).

As well, wide-ranging indicators are currently used to measure and track progress regarding resilience as a means to cover different aspects of the studied systems. There have been some attempts to view the various types of impact and response indicators in terms of their relevance to planning (Bizikova et al., 2015; Bousquet et al., 2016; Department of Environment, Food and Rural Affairs, 2010; Organisation for Economic Co-operation and Development (OECD), 2013). Moreover, several frameworks for indicator selection have emerged, aimed at simplifying the process of choosing relevant and understandable suites of indicators for particular policy applications, and, equally importantly, to ensure they will provide information that can be effectively linked to implementable decision-making processes (for example Weber et al., 2015; Moraci et al., 2016).

Through the lens of agriculture, in this paper we look specifically at the challenge of linking indicators from different sectoral perspectives with decision-making frameworks and policies for agriculture, climate change, species and habitat protection, infrastructure and public health. We consider the following questions:

- What are the critical information needs for a variety of sub-national and national policy-makers in terms of indicators for addressing different challenges and responses to climate change?
- What specific indicators can be used to monitor issues related to climate change resilience, such that they best represent decision-maker information needs?
- What are the challenges that limit the utility of the identified indicators for decision-making?

With a focus on local climate change impacts and needed responses, this paper identifies a suite of indicators to address resilience in agricultural landscapes. We provide details on the methodological approach, followed by listing the outcomes of indicator selection. Finally, we discuss guidance regarding general features of indicators that make them useful for policy and planning communities, and list future research needs.

1.1. Methods

This work builds on a multi-year participatory project that engaged decision-makers and other stakeholders in a review and assessment of priorities associated with future extreme weather events in a rural agricultural area (Waldick et al., 2015). As part of this process, a detailed mapping of the regional agricultural system was developed, representing important drivers of change such as climate, environmental, social and economic consequences and responses for the region. To expand on that work, this study engaged a broader array of sub-national and national decision-makers to identify potential indicators to characterize system resilience and fill critical information gaps for regional planning communities. Indicators were considered and defined based on the combined knowledge of participants around frameworks and policies in the study region, information priorities, relevance for decision making and pragmatic issues relating to data availability. This study includes a range of indicator types that represent the interests of agricultural, biological, human health and other disciplinary areas. It also examines differences and similarities among the various sectoral priorities according to their stated objectives.

1.1.1. Study region

The study is located in the eastern portion of the Province of Ontario, Canada (Fig. 1). This area, referred throughout the paper as a region, is bounded along existing jurisdictionally defined lines, each representing several layers of political (municipal, provincial and

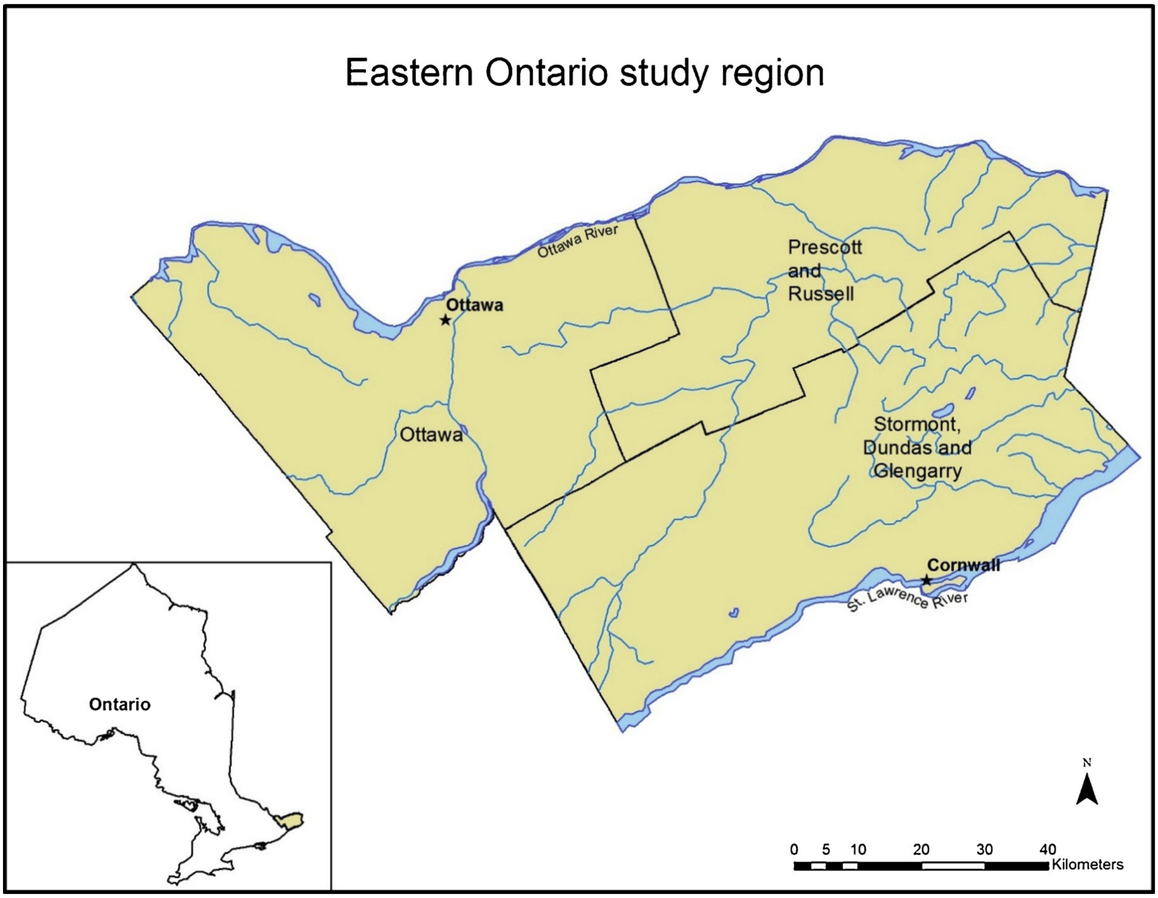

Fig. 1. Study region.
Created by the authors.

federal governments) and management bodies (conservation authorities, health units, non-governmental and sectoral organizations). In this setting, region-wide actions are only achievable through co-ordination across the different levels of government and other groups. Resilience building would be beneficial in this context if it enabled coordinated actions instead of only relying on autonomous and uncoordinated farm-level/local actions.

The study region is large geographically (842,363 ha), chosen to capture a mixed rural perspective on climate change adaptation planning by including rural land use planning, urban growth, agricultural productivity, water management, human health, etc. The region is centred on agricultural production and is potentially highly vulnerable to climate change due to, for instance, a reliance on rain fed crops. The region is also undergoing major socioeconomic changes that are related to a diverse assortment of internal and external drivers, including a relatively low level of competitiveness compared with farms in other parts of Canada, ongoing demographic shifts associated with an ageing population, and declining infrastructure and environmental systems (Anton et al., 2011, 2013). These issues have concomitant impacts on regional economics, population health, and environmental features, values and processes (Waldick et al., 2015).

1.1.2. Approach to Indicator Development

The indicator set was developed using a five-step participatory process centred on stakeholders' involvement, as follows:

Step 1. Initial Inputs and Priority Areas to Frame the Indicators

Fig. 2 outlines the framework used to define the inter-connected components within the study region (Waldick et al., 2015). This system was developed based on input from stakeholders active in the study area to identify potential impacts of greatest concern including climate change in the study area. This framework also helped position the local agricultural production systems within a broader socioeconomic and policy context (as also suggested by Bousquet et al., 2016). In this way, each of the categories shown in the system map represent potential pathways of vulnerability, adaptation action and/or mechanisms to introduce adaptive capacity and resilience that can be linked to specific sectoral policies.

The system map served as a basis to guide the identification of priority areas/themes for indicator development. The system map and the themes were developed with input from 119 stakeholders including policy-makers and researchers with interest in agricultural settings in the study area during a three one-day workshops. Prior to the workshops, the participants were provided with a 12-page hand-out summarizing current trends and projections up to 40 years for the region for climate change, performance of the agricultural sector, demographics, and environmental issues such as biodiversity, soil quality, water quality and quantity and forestry. Each of these areas was represented by a sectoral expert who also answered participants' questions. The workshops included a mix of group work and plenary sessions; each participant had the opportunity to submit their feedback individually by email or by filling a feedback form that was left with the researchers.

To identify the stakeholders, the research team comprised from the authors of this paper and additional collaborators identified and contacted stakeholders active in the study area through regional government offices (municipal, provincial, federal) and by the use of local farming directories. Additional stakeholders were identified through snowball sampling (Atkinson and Flint, 2001). In total, 138 contacts were identified and invited to participate in the workshop in Step 1. From this contact list, 119 stakeholders participated in the workshop in the Step 1 to develop the system map and the selection of themes/issue

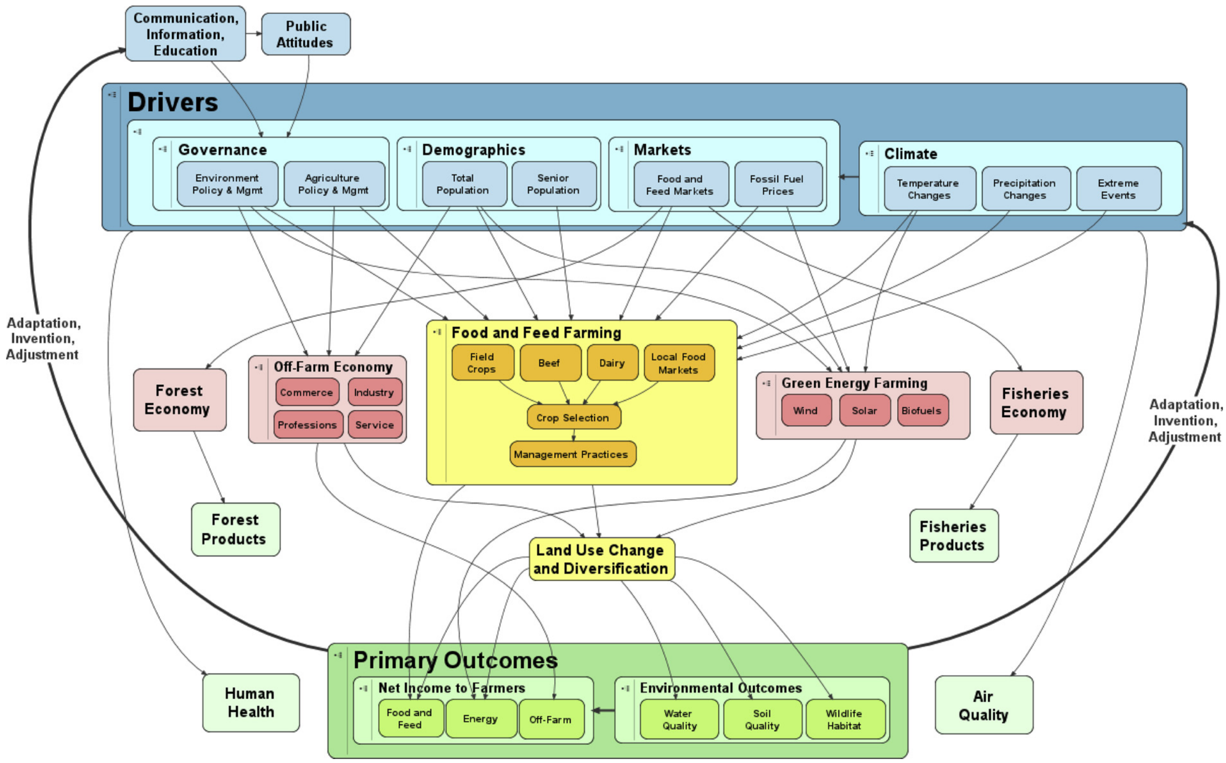

Fig. 2. Systems diagram showing key drivers and their pathways of influence (Waldick et al., 2015).

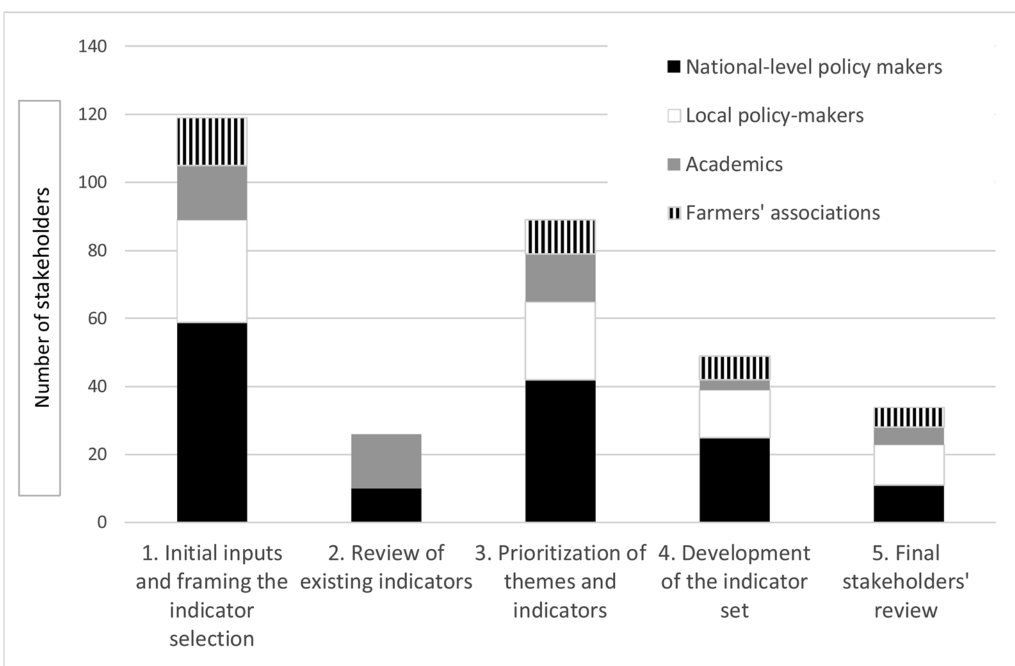

Fig. 3. Overview of the stakeholders' participation in each step of the methodological approach.

areas. A summary of the stakeholders' participation across the five steps is presented in Fig. 3. Overview of the indicator selection criteria, methods used and the number of selected indicators across each step of the methodology is presented in Table 1.

Step 2: Review of Existing Indicators

A literature review was conducted to establish information needs and generate a reference database of potential indicators for each of the themes identified in the system map. For this step, a smaller number of stakeholders were invited to participate, only those individuals who had previously indicated an interest to work with the literature on indicators during Step 1. 16 academics and 10 national policy-makers participated. Indicators were drawn from peer-reviewed and 'grey' literatureThe purpose of Step 2 was not to critically examine the indicators, as this had been completed by the leading agencies that published the reviewed literature. Rather, indicators on this initial list were assessed for their suitability to address the potential information needs of the stakeholders identified in the themes of the system diagram during the workshop in the Step 1. This included diverse array of issues

Table 1
Overview of the indicator selection criteria, number of selected indicators and methods used during the five-step participatory process.

Step	Indicator selection criteria	Number of selected indicators	Methods used
Initial Inputs and Priority Areas to Frame the Indicators	The themes were selected to cover potential impacts of greatest concern in the context of climate change in the study area.	No indicators	Stakeholders' workshop
Review of Existing Indicators	Published and grey literature reporting of potential indicators related to the chosen themes. This included indicators related to climate/climate extremes impacts, vulnerability, adaptation, and resilience, with a focus on issues for human health, agriculture, and rural areas.	72 indicators	Literature review
3. Prioritization of Themes and Indicators: Online Survey	Relevance of the indicator to track changes and the nature of the impacts and interactions between climate change and rural well-being in environmental, agriculture, socio-economic and built/infrastructure systems.	51 indicators out of the 72 identified in Step 2	On-line survey
4. Refinement of the Indicator Set	Acceptability of the indicator within the agricultural sector and other involved sectors to reduce sectorial impacts and/or improve resilience to climate change in the study area Comparability of the indicator between the areas of the study region and other areas in the province and the country	39 indicators out of the 51 identified in Step 3	Focus groups
5. Final Stakeholders' Review of the Indicator System	Data availability for the indicator: Data sources/agencies with the relevant data are identified and data for the indicator can be accessed publicly or through data sharing agreements Data are not available, but data collection for the indicator can be included in the current monitoring system/surveys.	36 indicators out of the 39 identified in Step 4	Stakeholders' workshop

such as climate change impacts, vulnerability, and/or adaptation and resilience per each theme of the system diagram. In total, 72 potential indicators were selected. Details on these indicators are included in Bizikova and Waldick (submitted)

Step 3: Prioritization of Themes and Indicators: Online Survey

The importance and relevance of this first set of indicators was established using an online survey. The Survey Monkey™ survey was pilot tested and revised, after which it was sent to stakeholder participants (total 119) from Step 1. Revisions included question order and providing an option for 'no response', given that policy-makers represented sectoral interests. 89 surveys were completed (for details see Fig. 3).

The survey collected general information regarding a respondent's sector, field of work, geographic area of interest, extreme weather priorities and measures, environment and health priorities, land cover/management, farms and production, transportation and connectivity, and demographics. The survey gathered detailed information regarding the relevance of the 72 potential indicators that could be used to track changes and the nature of the impacts and interactions between climate change and rural well-being in environmental, agriculture, socio-economic and built/infrastructure systems from now till up to 40 years. The same time frame was used in Step 1 to introduce current and future trends. Response choices included (scores 5–0): extremely relevant, very relevant, somewhat relevant, not relevant, and no comment. In addition to the scoring, the participants were provided an opportunity to add indicators or comments regarding the scored indicators.

Outcomes of the survey were used to identify the most highly ranked indicators. This included indicators that the average score was higher than fifty percent. From the 72 indicators collected from the literature in the step 2, fifty-one indicators were identified. This list was further discussed in a series of focus group sessions described in the Step 4. These discussions were arranged for stakeholders who indicated an interest in participating in the focus group in their submitted survey (Step 3).

Step 4: Refinement of the Indicator Set

The 51 highly ranked indicators were further examined in a series of focus groups. In total, eight focus groups involving 46 experts (participating in person and by remote connection) reviewed and assessed the highly relevant indicators from the survey (grouped within climate, populations, infrastructure, farm and environmental attribute categorizations). Discussions focused on reducing the number of indicators and specifying them further. The criteria for including the indicator in the indicator system included:

- Acceptability of the indicator within the agricultural sector and other involved sectors to reduce sectorial impacts and/or improve resilience to climate change in the study area
- Comparability of the indicator between the areas of the study region and other areas in province and the country

Using these criteria, the indicators lists was narrowed down to 39 indicators. For these indicators' definitions, thresholds and information on data availability was completed by the research team using the information from the focus groups.

Step 5: Final Stakeholders' Review of the Indicator System

Based on their previous engagement in the year-long process, all 119 stakeholders were again invited to participate in the final review of the indicator system. 34 individuals participated, with 30 representing the group that completed the survey and 4 stakeholders having contributed during Step 1, to develop the system map and identify the themes. During the final review, specific questions were explored, including whether (1) the suggested indicators involve specific data sources or agencies with data access or sharing agreements and (2) any of the indicators without available data could be included in their future monitoring/survey systems. This step led to the creation of the final indicator system addressing decision-making needs, with an indication of data access options and stakeholders' collaborations. The final indicator system included 36 indicators out of the 39 selected in the Step 4. Three indicators were removed because of lack of data and some were modified to address data availability.

2. Results

The indicator set is focused on priority areas defined by regional and local policy-makers (Fig. 2). In total, thirty-six indicators were selected and grouped into six themes (Table 2, including identification codes referred to in this section): climate change, population, farmland production activities, market and economy, and rural infrastructure. The indicators advance from generic measures (e.g. number of heat days or average rainfall) to regionally meaningful changes in the timing, extent, or features of impacts or outcomes compared to trends (e.g. the last five years or decades). Policy-makers perceive these indicators as an essential tool to identify gaps and areas in need of further investment. This was most evident in the context of current frameworks and policies to improve resilience in the region, which are currently lacking. The trends identified by the indicators also provide an important input for policy reviews on the relevance of the current actions, and guidance for

Table 2
Overview of suite of indicators within six themes.

Indicator code	Indicator	Definition and threshold	Details on data availability and calculations
C.	**Climate change -** seasonality and severe weather		
C.1	Changes in growing season	Agriculture – Seeding date (more then 15 days difference compared to provincial average for the last 5 years)	Data available; Alternative indicators: green up date (10–20 days after seeding); varies by crop and/or maple tapping date; bud date
C. 2	Late spring frost (date)	Date of the spring frost within the average frost days between May 1 and June 20;	Available; thresholds are crop specific ($< 0\,^{\circ}C$ for soy, $< -2\,^{\circ}C$ for corn)
C. 3	Extreme heat	Three or more days $> 32\,^{\circ}C$ threshold will be used; calculated per month	Data available
C. 4	Heat spell duration	Max number of consecutive days with daily max temperature threshold of 5 °C above normal, by month	Data available
C. 5	Wet spell duration	Consecutive wet days by season; threshold of above 1 mm will be used	Data available
C. 6	Drought frequency	Changes in annual length, by month thresholds by crops and compared to available moisture is 20% less than crop water requirement. This is based on provincial policy threshold	Data available
C. 7	Drought severity	Provincial policy defines current thresholds for drought severity. Threshold is changing in terms of timing or seasonality (it is becoming an issue in other seasons)	Data available
C. 8	Deficit/Excess water	Streamflow/discharge rates; the threshold is based on flood forecasting and warning with thresholds compared to last 10 years of water deficit/excess	Data available;
D.	**Demographics**		
D. 1	Agricultural producers as proportion of total rural population	Percentage and change compared to the provincial average for the last 10 years	Calculation; available, but reduced data availability with non-family/residential farms
D. 2	Rural inhabitants as proportion of total regional population	Percentage and threshold compared to provincial average	Calculation; definition of “rural” character varies
D. 3	Age of farmers	Average and compared to the threshold defined by the national retirement age	Available, but reduced data availability with non-family/residential
D. 4	Share of rural population more vulnerable to climate change	Percentage of rural population seniors/children, socioeconomic status, health status compared to provincial average for the last 5 years	Data gap; calculation; research required to determine availability
F.	**Farmland production activities**		
F. 1	Yearly agricultural output compared with long-term average	Per ha or kg compared to the provincial average for the last 5 years	Available; calculation
F. 2	Mix of crop type, perennial vs. annual	Proportion or total hectares compared to the provincial average for the last 5 years	Perennials available
F. 3	Livestock density	Animals/ha by type compared to the provincial average for the last 5 years	Data available
F. 4	Portion of farm infrastructure in floodplains	Percentage compared to the provincial average for the last 10 years	Data available, but processing required
F. 5	Portion of barns with air conditioning	Percentage compared to the provincial average for the last 10 years	Data gap, but it can be collected for the region
F. 6	Portion of land with tile drainage	Percentage compared to the provincial average for the last 10 years	Data available, but processing required
F. 7	Proportion or hectares of farmland under conservation, no-till, rotational grazing	Percentage or hectares of total land under production compared to the provincial average for the last 10 years	Available; only cover crop data available in census
F. 8	Manure management strategies	Prevalence by type based on the thresholds listed in provincial policies	Data gap; calculation
M.	**Market, Economy**		
M. 1	Percentage of farms with off-farm income	Percentage compared to the provincial average for the last 5 years	Data available through farm census, but data processing and additional data collection to cover all the farms in the regions
M. 2	Medium and average farm size with insurance coverage	Percentage compared to the provincial average for the last 5 years Based on the farm size defined by Statistics Canada	Data available, but confidentiality agreements need to be signed with insurance providers
M. 3	Level of debt per farm type	Average, median compared to provincial average and change over the last 5 years average	Data gap; calculation
M. 4	Gross domestic product in rural areas	Monetary value of all finished goods and services for bounded region compared to the provincial average for the last 5 years	Data available, but calculation required to exclude sharing economy
M. 5	Relative shares of small, medium and large farms	Percentage of small and medium farms from the total number of farms compared to the provincial average for the last 10 years	Data available
R.	**Rural infrastructure**		
R. 1	Road density in the flood plain	Percentage and length of roads located at the floodplain compared to provincial average	Data available, but data processing required
R. 2	Age and condition of the infrastructure	Roads, bridges, communications compared to the provincial average for the last 10 years	Data available, with a number of data providers and thus extensive data collection and assembling is required
R. 3	Portion of population with small/private drinking systems	Percentage not using municipal drinking water systems compared to the provincial average for the last 10 years	Data gap; calculation
R. 4	Frequency of drinking water shortages or contamination	Number of events per year compared to the provincial average for the last 10 years	Data available through drinking water advisories; threshold based on the Health Protection and Promotion Act

(*continued on next page*)

Table 2 (*continued*)

Indicator code	Indicator	Definition and threshold	Details on data availability and calculations
R. 5	Access, location, density of health emergency systems	Number and percentage of communities with below average rural provincial access to services compared to the provincial average for the last 5 years	Data is available by tracking access to point of care; data processing required
E.	**Environmental services**		
E. 1	Watershed buffer zone	Percentage shoreline permanently vegetated: 30 m high water; 120 m for certain wetlands based on the provincial policy	Data available, but data processing required
E. 2	Undisturbed land cover	Percentage or total hectares forest or wetland compared to the provincial average for the last 10 years	Limited data available and an alternative could be hectares of land cover under sustainable forest or wetland management
E. 3	Reforestation, deforestation	Percentage of land cover or total hectares change over the last 5 and/or 10 years average	Data available
E. 4	Rural land management and species biodiversity	Land fragmentation index and compared to the provincial average for the last 5 and or 10 years	Data needs processing and that has begun
E. 5	Erosion risk	Risk of soil erosion due to wind and water as percentage of total (agricultural or other) land compared to the provincial average for the last 10 years	Data gap; e.g., two-year peak flow; land use on clay soils
E. 6	Species range shifts (e.g., hantavirus, invasive)	Incidence of reported pests and disease with focus on emerging pests	Species specific; data gap; need to define “climate envelope” to capture model spread.

Table 3
List of policies and frameworks considered during the development and for the use of the indicators.

National policies and frameworks	Relevant indicator themes
Growing Forward Phase 2 (GF2) is a five-year (2013-2018) policy framework for Canada's agricultural and agri-food sector. http://www.agr.gc.ca/eng/about-us/key-departmental-initiatives/growing-forward-2/?id=1294780620963	Farmland production activities, Market and economy
Pan-Canadian Framework on Clean Growth and Climate Change is a plan for emission reduction and resilience building to adapt to a changing climate. https://www.canada.ca/content/dam/themes/environment/documents/weather1/20170125-en.pdf	Climate change, Farmland production activities
The Canada Municipal Rural Infrastructure Fund provides support for local infrastructure in urban and rural Canada. https://www.tbs-sct.gc.ca/hidb-bdih/initiative-eng.aspx?Hi=55	Rural infrastructure; Environmental services
AgriInvest and AgriStability Programs are income stability tools offered under the business risk management suite of programs; www.agr.gc.ca/eng/?id=1291828779399	Farmland production activities; Market and economy
Protected Species Act – aims to prevent wildlife species from disappearing, provide for the recovery of wildlife species that are extirpated, endangered, or threatened as a result of human activity, and also aim to manage species of special concern. https://www.canada.ca/en/environment-climate-change/services/environmental-enforcement/acts-regulations/about-species-at-risk-act.html	Climate change, Farmland production activities,
Provincial policies and frameworks	
Ontario Low Water Response ensures that provincial and local authorities are prepared for low water conditions; https://www.ontario.ca/page/low-water-response-program	Climate change, Environmental services
Agricultural Farm Management Plan aims to help managing agri business, production, marketing and, farm business diversification; http://www.omafra.gov.on.ca/english/busdev/agbusdev.html	Farmland production activities; Market and economy
Nutrient Management Act regulates nutrient management of agricultural activities to limit their impacts on nature and humans- http://www.omafra.gov.on.ca/english/nm/nm-act.htm	Farmland production activities; Environmental services
The Advanced Farm Management (AFMP) program is designed for farm business owners and managers to improve farms’ performance and sustainability http://advancedfarmmanagement.ca/	Farmland production activities; Market and economy
Ontario Community Infrastructure Fund is a long-term funding for small, rural and northern communities to develop and renew their infrastructure. https://www.ontario.ca/page/infrastructure-funding-small-communities	Market and economy; Rural infrastructure
Health Protection and Promotion Act provides or ensure the provision of the health programs and services; https://www.ontario.ca/laws/statute/90h07	Rural infrastructure; Environmental services
Riparian Zone Protocol aims to ensure beneficial activities in riparian areas to protect habitat and watersheds- http://acer-acre.ca/wp-content/uploads/2011/12/Riparian-Zone-Protocol.pdf	Farmland production activities; Environmental services

revising policies to address critical areas where sectoral policy needs to be coordinated. This was again seen as a way to better support actions and investments needed to improve resilience in the region. The relevance of the themes to national and provincial policies and frameworks are summarized in Table 3.

The indicators include some that are already available, and have data that is accessible, and others for which data are not available in the region. For each theme, the following sections describe the indicators, their relevance and implications for frameworks and policies, data availability, and current gaps in monitoring efforts within the six themes.

2.1. Climate change: seasonality and severe weather

Decision-makers recognized climate change as a driver affecting all of the conditions and decisions of importance in the study region (Waldick et al., 2015). Consequently, the indicators in this theme capture changes in the seasonal expression of weather (C. 1–2) and extreme weather events (C. 3–8). These are likely to be responsible for direct risks to critical sectors (e.g., agricultural production, roads or other infrastructure, natural environment, mortality) and indirect impacts (i.e., water availability, erosion, land use, biodiversity, income, morbidity). Given the specific characteristics of the climate in the region compared to rest of the country, indicator thresholds must be based on long-term averages for the province as well as for the study region.

By focusing on change rather than absolute values, information would be provided at a high level of resolution to be relevant to the local setting—with each indicator having an accompanying critical threshold or value associated with specific outcomes. For example, with respect to agriculture, changes in growing season length (C. 1 and C.2) depend on the crop in question, differing according to the specific phenological requirements (Brevedan and Egli, 2003; Nielsen, 2000; Reid et al., 2007). Conditions affecting planting (seeding) date or

growth and flowering responses (or tolerance) to heat and drought (C. 3 -, C. 4, C. 6 and C. 7) will differ depending on the developmental stage of different crops. Extreme heat thresholds are defined according to the impact on relevant crops for the region; for example, air temperatures exceeding 32 °C over extended periods during the flowering period (C. 3) affects yield for most varieties of corn (Schoper et al., 1987). Similarly, changes to extreme heat events and shifts to earlier onset of the growing season (C. 1) by 15–19 days in the study area are expected to affect maple syrup production (Houle et al., 2015).

Extreme heat risk (C. 3) also has serious human health impacts that must be considered in terms of how they will change rather than just absolute threshold values. The threshold for an extreme heat event is defined by Environment Canada as three or more days over 32 °C, by month and it is relevant for the region. However, heat can also affect other attributes at a variety of other 'extreme thresholds' for both human health (Cheng and Berry, 2013; Yusa et al., 2015) and production systems. Moreover, the effects of extreme heat can be related to the time of appearance, where earlier seasonal heat shows greater effect because of less acclimatization (Magrigano et al., 2015). Extreme heat affects employment and working conditions, as well as general living conditions for agricultural and rural-based populations. To date, considerable research has focused on the indicator of excess mortality as a function of temperature extremes. Although the literature review identified more research regarding urban centres, the mortality effect of extreme heat in rural areas was found to be similar to urban centres (Magrigano et al., 2015). While excess mortality may be a direct effect of extreme heat, health outcomes are also differentially affected by air quality, health status, age, gender, income and social facilities. Some risk factors in rural areas include social isolation, poor health and age.

Indicators in this theme provide important information about major risks in relation to features beyond health alone; this includes direct relevance for diverse sectoral decision-makers active in agriculture (production and management; indicators C. 1–2), and environmental management (eg., water management; C. 5–8), infrastructure (eg., air conditioning; access to public health support; C. 3–4), and their implications for targeted programs and investments in the study area The indicators provide opportunities for decision-makers to design programs to support farmers' autonomous responses by assisting, for example, in selecting crops with better heat tolerance, accommodating changing seeding days and adjusting to droughts/frost etc. The indicators provide specific information for, as an example, federal and provincial drought response policy as well as provincial guidelines regarding the occurrence of low water (note: this includes setting thresholds of local relevance). For such policies, indicators of drought frequency (C. 6), severity (C. 7) and water excess/deficit (C. 8) were seen to provide important information for direct use in water supply management. This includes policy actions such as conditions for restricting water use/conservation to reduce non-essential use, as well as establishing criteria around irrigation for agriculture.

2.2. Demographics

Demographic characteristics are an important source of vulnerability from the resilience point of view. Indicators capturing potential increased vulnerabilities of segments of the regional population include measures of isolation (D. 1–2), age (D. 3), and socio-economic/health status (D. 4). While related, previous demographic-related indicators focused on more immediate priorities, notably those related to financial impacts for farm income due to crop or infrastructure damage. Our indicators were seen to provide more specific targets and potentially refined planning and policy-making, for example to increase access to health care workers and other supports for elderly members of the farming community who may be geographically isolated.

For example, rural dwellers rely to a greater extent on self-sufficiency to resolve emerging climate-related impacts than their urban counterparts (the latter having access to a larger tax-base and institutional resource base to support adaptive measures) (Karrholm et al., 2014; Magrigano et al., 2015; Williams and von Stackelberg, 2011). This isolation can be captured using readily measurable indicators, for example the proportion of agricultural producers and rural inhabitants as a percentage of the total regional population (D. 1 and D. 2). It is of note, however, that newcomers to rural areas may be more dependent because of previous experiences with an urban resource base (Karrholm et al., 2014).

Other indicators consider potential acceptance, influence, and ability (or willingness) of different segments of the population to prepare for and respond to potential risks. Indicators D. 3 and D. 4 capture the more vulnerable segments of the population when broken down by age (seniors and infants/children versus working age inhabitants), socioeconomic and health status (low income and those with chronic diseases and compromised immune systems), and Indigenous peoples (Warren and Lemmen, 2014).

2.3. Farmland production activities

Given the importance of agriculture in our study region, the core of the indicator set remained focused on farmland production activities, defined in terms of the risks they create or how they improve resilience. These include output (F. 1–3), infrastructure (F. 4–6), and management strategies (F. 7–8). This set of indicators was seen as useful in providing information about the state and potential agricultural responses to climate vulnerabilities, as well as broader ecosystem and community level resilience. Indeed, farmland production activity indicators capture potentially important information necessary for policy-makers to identify gaps or amend existing policies such that measures may increase resilience to emerging risks – both within and beyond the agricultural sector (Tobin et al., 2015). For example, output and farm management includes indicators for livestock density (F. 3) and manure management (F. 8), both of which also provide weather-specific insights into other sectoral policies (e.g., risks to public health – Yusa et al., 2015; wildlife conservation - Tobin et al., 2015). Moreover, the portion of farms with air-conditioned barns (F. 5) can be used to reflect the ability of farmers to cope with extreme heat, both for their livestock as well as for themselves, thus making this a useful indirect indicator of resilience to heat stress.

For this theme, relevant policies and frameworks include both national and provincial jurisdiction. At the national level, the indicators provide critical information as part for the review process for the next phase of federal agricultural programming (Growing Forward, the Federal Government Agricultural Program) to manage risks and promote robust adaptive strategies. At the provincial level, the indicators' trends feed into specific policies on nutrient management and agricultural farm management. In addition, the indicators interact with those in other themes, to provide unique information for the national and provincial agricultural planning. For example, increasing excess water (C. 8), decreasing area of land with drainage systems (F. 6) and certain manure management strategies (F. 8) point to the increasing water pollution and choices for policy-makers to improve drainage systems and/or encourage manure management with limited run-off, both of which have potential effects on environmental services (Section 2.6).

2.4. Markets and economy

Economic metrics are well established in the agricultural literature to measure the sectoral and regional performance in order to indicate vulnerability to climate change (Public Health Agency of Canada, 2010). Indicators targeting the economic situation for agricultural producers consider financial status (income stability and debt; M. 1–3), contribution of agriculture and to regional gross domestic product (M. 4), and changing farm size within the region (M. 5). Consequently, indicators were identified in forms that were directly (M. 2 and 3) and

also indirectly affected by severe weather (M.1, M. 4 and 5). Climate extremes in particular were viewed as important, as they have the potential to affect farm or family income through: direct crop losses from extreme heat, drought, high precipitation, storms, flooding, or wildfire; working conditions; and/or potential less direct effects, such as increased costs to producers and households to ensure acceptable water quality, quantity and health care costs. Income trends could account for both on- and off-farm income sources (M.1), including insurance coverage (M. 2) and levels of debt (M. 3).

The economic indicators also took into account potentially changing farm structure (M. 5), associated with the trend for small and medium size farms to be taken over by large-scale farm operators. The shift from smaller to larger farms provides two important types of information; on the one hand, small farms tend to be more resilient to climate related impacts because they are more diversified in their production, versus medium-scale operations, but these often rely on purchasing insurance to compensate for losses (M. 2). Thus, policies that promote conventional insurance policy will likely be of limited relevance for smaller sized operations and may discourage resilience through a reduction of diversified agriculture within the region. Direct actions may also be taken by providing programs for farm income support or by providing farm scale risk management strategies (to respond to M.1–3). The nuanced interconnections between these indicators and farm management decisions (Section 2.3) were seen as beneficial for identifying appropriate capacity-building efforts and educational activities for farm operators and managers, which may be implemented by provincial agencies beyond the agricultural sector.

2.5. Rural Infrastructure

Policy-makers discussed rural infrastructure in terms of roads (R. 1–2), water management (R. 3–4) and emergency systems (R. 5), whereby indicators focus on identifying and prioritizing infrastructure risk based on location within a vulnerable area. Road accessibility and conditions (R. 1–2) was viewed as important from the perspective of economics and safety, since closures affect the movement of goods as well as access to social and other emergency management services (e.g., hospitalization or ambulance and fire services, R. 5)). Interestingly, water, which is traditionally considered a stand-alone category of indicator, was considered in the context of infrastructure with emphasis on water quality and availability (R. 3–4). Its position as an indicator of infrastructure was viewed as the portion of the population with small/private drinking water systems (R. 3), as these systems are particularly susceptible to both the direct (water quantity) and indirect effects of reduced water quality (R. 4) (Moffatt and Struck, 2011) during extreme climate events. The agrarian nature of this region meant that the infrastructure indicators were most closely linked to those in the farmland production activities (Section 2.4), particularly regarding flood plains (R. 1), although the implications for access to health services (R. 5) and other support are also likely to be central to resilience during periods of severe weather.

Indicators for rural infrastructure were of great interest to policy-makers from across disciplinary areas, as they are directly built and maintained by authorities at local, provincial and national levels. Policy-makers particularly emphasized the importance of using medium term (10-years) time horizons to detect change, as infrastructure degradation often happens over longer time than other measures, such as farming practices. For such indicators to be meaningful, these indicators need to measure both the current status and change of rural infrastructure (for example R. 2 and 4), and the projected impacts under climate change, so that appropriate allocations by provincial and national programs may be discerned and acted upon.

2.6. Environmental services

The natural environment was considered from the perspective of supporting ecosystem services such as water and wildlife protection. These include measures of habitat size and quality (E. 1–4), seen as important contributors to resilience regarding the contribution to maintaining natural processes. In terms of regulating services, resilience was largely seen with respect to how measures could provide early warning for policy-makers regarding risks of soil erosion/sedimentation (E. 5) and emerging diseases (E. 6). Some of the environmental service indicators also relate to provisioning services associated with agricultural production activities, Section 2.4 (F. 1–4). Cultural and recreational services were not included in the indicator set based on the policy-makers experience that they have a limited potential in this region to address resilience; for example, the potential of increasing income from recreational activities was not seen as viable. In addition, recreational activities lack coordinated policy; they are the outcomes of small-scale autonomous efforts.

Policy-makers viewed indicators of supporting services as the most important, because they represent the most direct measure of risk and resilience linked to planning and decision-making efforts; they were also viewed preferentially since they are already used in impact assessments (e.g., for investments and regional planning). This includes, for example, measures of the extent of the watershed buffer zone (E. 1), land cover status (E. 2) and forestry (E. 3) providing habitat for listed and protected species (e.g., migratory birds, species-at-risk), as well as providing benefits in support of pollinators (biodiversity services). Other benefits are associated with reducing the spread of weeds and invasive species.

Environmental services, considered in terms of land use, was also related to human health where land clearing (E. 2 and 3) in combination with exposed agricultural fields or other land) can increase potential morbidity and mortality through air borne contaminants and species range shifts(E. 5 and 6, respectively). Consequently, measures such as the area of undisturbed land cover (E. 2) can be used to capture vulnerabilities (and identify vulnerable areas) associated with pathogen and disease risk, as well as damage or degradation of fish and wildlife habitat. Another land use indicator is the proportion of reforested versus deforested area (E. 3) in a region, with similar implications on health, water and biodiversity.

Rural land management can be used to enhance resilience and reduce risk directly, such as activities to change land cover (E. 1–4), but also for less direct measures such as the types of manure management practices (F. 8). These measures, as noted earlier, were selected because of their strong policy and management linkages which allow actions to be defined at local scales in order to address concerns for poor outcomes in human health and ecosystem services. However, as also noted earlier, these interventions tend to be managed at higher levels of government through strategies such as provincial riparian zone protocols (e.g., buffer zones and reduce the potential for erosion) and reforestation programs, along with national protected species acts and management plans that may reduce land fragmentation.

3.7 Data Availability, Gaps and Feasibility in Use of Indicators

Data availability is an important criterion in considering the feasibility and suitability of each indicator in the set. The 36 indicators reflect identified critical issues for the assessment of resilience to climate change and could be used by regional decision-makers to guide the development and review of strategies, policies and investments. However, only a sub-set of these indicators may be put into use due to data availability challenges. Of the 36 indicators, approximately half could be adopted readily in the study region, using readily available data (Table 2). This was mostly due to earlier work in this region, where data and trend information had been compiled (Waldick et al., 2015). Some of these data could be easily accessed from major public data providers such as Statistics Canada, Canadian Forest Service and others, although the periodicity of collection may be limiting in itself (e.g., five plus years in the case of Statistics Canada).

For the remaining indicators, data were either missing or required considerable additional processing before being suitable for use. In

some cases, the local authorities did not have access to the type of expertise necessary for this additional data processing. And, despite advances in the production of open, spatially explicit crop inventories (e.g., Salehi et al., 2017), the most problematic information gap is in accessing detailed farm production and economic performance data; increasingly, government statistical information is becoming more difficult to analyze on the farm basis (Poon and Weersink, 2014; Poon et al., 2011) to avoid privacy issues. Similarly, privacy issues and reluctance to share data were limiting for accessing economic data, notably those regarding insurance and debt. This gap needs to be addressed, potentially through the establishment of collaborative data sharing agreements between government and the insurance industry, and/or other entities.

On the other hand, improved collaborations with universities for data sharing was addressed in part through this work; in undertaking this regional study, more refined data was created than would otherwise be accessible (e.g., more extensive and detailed data on agricultural cover, wildlife species range shifts and rural land use). Although combining data from different sources is important, in many cases, data required for some of the indicators is simply not available in the correct form, time step or scale. This means that indicator values can only be calculated for a subset of farms or farm types within the region. Nevertheless, despite the various gaps and data limitations, the policy-makers indicated that the indicators with available data provide a considerable amount of information to better understand how different segments of society in this region are affected by and can respond to climate change risk, thereby enabling them to create more regionally relevant policy and investments guidance.

3. Discussion

Socioecological resilience, in our context, requires that environmental, social, and economic conditions be considered together to ensure collective resilience of the rural-agricultural communities to climate change and other drivers. The key objectives of this study were to work with policy and decision-making communities in the study area to prioritize and define critical information needs to track climate resilience. This necessarily emphasized information of direct relevance for specific policy, planning and management objectives. By coordinating this process with different practitioners (with different roles in planning; i.e., science, policy, planning), we were able to identify large areas of overlap in information needs irrespective of sector or the type of authority. These areas of shared information needs offer important opportunities for collaboration and information sharing to improve planning processes, as well as possible ways to reduce the costs to individual groups to undertake monitoring, analysis and reporting. The information needs for decision-makers to track resilience can, for the most part, be achieved with information that is often already available. The sharing of indicators and information also allows different levels of decision-makers to build on this information to address more complex challenges, such as cumulative effects, resource shortages, and even managing issues of data availability.

3.1. Information needs of policy-makers for addressing challenges and responses to climate change

The approach taken by policy-makers emphasizes their need to improve understanding of ways climate change will manifest its impacts on agriculture. While studies focus on resilience (Tyler and Moench, 2012; Intergovernmental Panel on Climate Change, 2012), the first requirement of the policy-makers was to assist with defining the pathways of risks for the complex interactions between climate change impacts, local and regional vulnerability, and responses to build resilience. For policy-makers, such understanding provides highly relevant information on critical impacts and ways of improving resilience that could be beyond their narrow sectoral and/or jurisdictional focus. These interactions occur at fine scales of time (a couple or few years) relevant for policy and decision-making processes but are not addressed in climate change analysis (or data) that considers changes over 20- or 30-year time periods over a projected span of 100 years. The indicators chosen by our practitioners were selected for their ability to track critical changes and interactions between temperature or precipitation extremes and desired management or policy outcomes. They also provide important information when used with climate model projections to identify vulnerabilities, either for the existing state or the capacity (which could include resources) to respond. This was as important for local producers as it was for other regional authorities, all of whom must respond and prepare in different ways. For example, a longer growing season may be beneficial if it extends the growing season for crops, allowing earlier planting dates; however, these same changes can increase health risks if the number of life cycles (and therefore population density) of pest and disease carrying organisms increases over the summer period (Yusa et al., 2015). The use of a broader system perspective was crucial in allowing policy-makers to track and measure pathways of risk according to the myriad of factors that need to be considered over for a 4–5 year policy and planning cycle, allowing actions to be more clearly defined than is possible using the more nebulous and long-term timeframe of climate resilience.

In our study region, the system perspective was selected because it helped to explicitly identify policies from diverse sectors that would impede, interact, or otherwise affect important risk and resilience pathways. The types of policies that were considered in this study covered major features of local agricultural systems, as well as critical interactions between these and non-agricultural drivers, whether related to infrastructure (loss or changes), human health (disease risk), or environmental factors (eg., water shortages or contamination risks). When looked at collectively, this information can identify the potential for compounding risk by providing new information that can be used in building greater regional resilience. This was also viewed by decision-makers as a mechanism to help increase policy relevance by identifying policy gaps and areas needing further investment, and by pointing out negative interactions between policies.

3.2. Indicators for climate change resilience best representing decision-maker information needs

The system perspective has the interesting element of placing climate change and climate change impacts in a relatively small sub-set of direct indicators, emphasizing instead the impacts of weather on vulnerable components of the system. As such, the indicator set was defined to cover the challenges faced by the various sectoral policy-makers. The importance of understanding risk in terms of impacts cannot be adequately stressed; each sector faces the similar challenge of trying to account for vulnerability in the absence of other important contextual information on economic, social and environmental change. The limited resources available to regional decision-makers can be offset by the pooling of capacity to respond to climate change impacts, and allowing each to more effectively tackle shared problems (Waldick et al., 2017). In this context, the indicator set serves to increase awareness and understanding around previously ‘unknown’, perverse, or poorly defined policy gaps. It may also prove useful for local government offices to influence or request support from higher levels of government (e.g., national/federal and provincial), by pointing out current limitations for local decision-makers in addressing important drivers and risks that lie outside their jurisdiction.

From a practical point of view, the indicators may be used individually by decision-makers to help assess some aspect of their sectoral performance within the context of climate change, or to evaluate progress with policies in building desirable resilience. The multi-disciplinary nature of this set also means it may be used to define alternative metrics by combining direct and indirect impacts in order to broaden otherwise narrow policy perspectives. From solely the

agricultural perspective, for example, the various indicators drawn from the literature, while appropriate to the region, need to be adapted to capture the key drivers and how they are expressed within this particular socioecological setting, with its particular circumstances and conditions. Individual indicators of yield effects and management can then be used for agricultural policy to manage responses or impacts on locally grown crops and associated farmland management accordingly. For instance, indicators for the duration of heavy rainfall during seeding and harvest periods indicate that late seeding varieties may be preferable to those requiring earlier planting that may be delayed by a wet spring. However, when heavy rainfall events are considered part of the indicator set, this provides more detailed insight into other types of vulnerabilities such as potential effects on rural infrastructure including roads, which has implications for shipping and receiving of supplies and goods, or access to social or health support. The value of using an indicator set is that it allows agricultural policy-makers to consider how other sectoral effects may interact with agricultural systems in light of climate change; this adds a completely new element of planning that can promote greater resilience.

Indicators are typically considered with respect to a threshold of effect. The use of threshold-based indicators can better track relationships between different sectoral drivers and policies and a given impact. For example, a suite of indicators—which includes both direct and indirect measures—may identify patterns that were not captured by sector-focused indices. Income was considered both from the perspective of the farmer and the farming sector: first, in terms of impacts (specifically losses) due to particular weather events, such as delayed planting date for a particular crop; and second, from the point of view of policy and planning communities, where the interest is in understanding the burden of risk and level of resilience that the rural farming community carries. The latter case relates to the health of the individuals as well as the ability of the agricultural sector to financially withstand low-income years or to implement on-farm adaptation actions. By combining more standard production indices that consider climate impacts on yield and management with health based income thresholds, decision-makers working in public health and other sectors in these rural settings are better able to broaden the scope of what is considered as vulnerabilities and gaps in resilience that will need to be addressed.

The idea of coordinating efforts among policy-makers from different sectors in Canada is most significantly challenged by the nature of the decision-making structures themselves; these typically operate according to specific sector-based programs (and funding), which provide limited or no support for key types of capacity that communities need to increase their resilience to climate change impacts. Of the support that does exist, most is tied to narrowly defined sectoral objectives, for example manure management (provincial level) and infrastructure and transportation code improvements for flooding and water flows (national and provincial levels). One of the benefits of an indicator set is that it allows these narrowly defined actions to be contextualized in light of broader resilience needs. For example, in the case of manure management and managing water flows, broader regional objectives may be defined to target those areas where the indicators show vulnerabilities to be greatest. This is only possible with the involvement and coordination of local practitioners, and requires that policy-makers develop appropriate indicators to track and capture the types of interactions and linkages that have the biggest potential benefits to resilience building, whether through direct, indirect or sector-based (e.g., ranging from public health to infrastructure, ecological services and other biophysical features in the environment).

3.3. Challenges limiting the utility of important indicators for decision-making

For the most part, the most accessible information regarding extreme or shifting weather patterns are discussed in general terms, by sector (Lemmen et al., 2008). This is, in part, because climate change continues to be viewed as one of many issues affecting a sector, rather than an overarching issue compounding and complicating existing socioecological priorities. This has the unfortunate consequence of decoupling the processes for identifying risk from those that deal with implementation and management (i.e., investments and financing). To date, most municipalities or regions that have undertaken adaptation planning or risk activities in Canada have been reliant on summary data, too coarse for calculating the types of indicators represented here (e.g., month, season or year using Pacific Climate Impacts Consortium Plan2Adapt Tool [https://www.pacificclimate.org/analysis-tools/plan2adapt]). To do otherwise requires access to experts capable of undertaking the not insignificant work of transforming daily climate model data outputs into indices of meaningful spatial and temporal scales.

Access to appropriate data is not limited to the climate model projections, but also by other privacy and cost factors. For example, to consider impacts on the health of individual farms and sectors, there is the issue of data uncertainty, which results from the methods used to aggregate the data to mitigate privacy concerns (e.g., level of debt and insurance rates must be expressed at coarse scales without spatial context). Such datasets are not validated by the relevant government and non-government sources, which introduces new sources of error that confound their use for local scale impact analysis. Moreover, with the growing heterogeneity of the farm sector, concerns about the utility of Canada's agricultural data sets have been raised repeatedly by Poon et al. (2011) and Poon and Weersink (2014). Unsurprisingly, no strong precedents exist for their use by regional decision-makers.

Despite the various data and uncertainty limitations, the practitioners involved in this study were able to identify a significant number of metrics that could adequately provide information to inform their policy and program decisions. This is noteworthy because climate change is in itself uncertain, making it important to understand the nature of how weather and associated impacts will change, rather than predicting or quantifying them in absolute terms. In fact, the primary contribution of this sort of multi-disciplinary indicator set is that it combines impacts from across different sectors, not in absolute terms but in relative terms. This allows important considerations to be identified, prioritized, and helps to 'flag' those elements within the socio-ecological system that will be most vulnerable to climate change (not just in terms of the individual impacts on a single sector). The indicator set clarifies some of the relationships between policies and management choices and resilience from a broader perspective. One of our observations is that the roles of different government agencies, industry and academia are complementary and if coordinated could contribute missing links in the evaluation of vulnerabilities, risk, and resilience at the regional scale by working across the various scales and priorities. For our study, we faced a major gap in accessing economic data and wildlife data. This limited our ability to address many of the environmental and social elements of interest, yet, the practitioners involved in this study were able to identify, in many cases, suitable surrogate indicators to provide some of the information required. In jurisdictions where subnational governments work with diverse stakeholders with the specific objective of coordinating risk management and adaptation planning, established collaborations facilitate data collection and sharing (see for example, the European Union's Climate-Adapt Program - http://climate-adapt.eea.europa.eu/). This observation, and the European example of a coordinated arrangement, indicate that new processes and relationships need to be developed (and sustained) in order to create a functioning monitoring system both for data collection and processing.

The results of this system-based indicator approach point to the reality that monitoring and risk assessment of climate change impacts, adaptation capacity and resilience are cross-sectoral efforts that are most effectively done together. In bringing together different departments and authorities, an achievable assortment of complementary

system-based indicators were identified. This array was selected because it would enable an approach to planning through the development of targeted activities capable of improving resilience. It also offers a vehicle for bringing together different sectors to enhance the diversity of information needs that may be met with limited resources.

4. Concluding Remarks

In this paper, we present an approach to indicator development that considers critical aspects of resilience centred on agriculture. Although this work initially focused on agriculture, there was substantial concordance between the priority indicators defined by this sector and those from public health and the environment. The similar data and information needs among the sectoral bodies we consulted are representative of the scale at which they operate; agriculture, public health, environment, and land use planning practitioners necessarily focus on localized scales.

Information and resource sharing among sectoral authorities could be used to greater effect than is possible in isolation. More coordinated planning between seemingly disparate sectors, like health, agriculture and transportation groups, would provide opportunities for pooling resources, like budgets, which are often limiting at the landscape/regional scale.

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